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Production and quality of biomass fuels from mechanized collection and processing of vineyard pruning residues

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ABSTRACT

Vineyards cover about eight millions of hectares worldwide and their annual pruning generates a large amount of ligno-cellulosic biomass, potentially available for industrial and energy use. Commercial pruning residue harvesters are now available, which may allow cost-effective recovery. The study aimed at determining the quantity and the quality of pruning residues potentially derived from vineyard management. Data were obtained from 17 fields in Northern and Central Italy. Fields were harvested with seven different machines. The experimental design adapted to the necessities of field trials, but was adequate for testing the main sources of variability. Net residue yield varies around 1 oven dry tonne per hectare, with minor differences between grape varietals and harvesting technologies. Losses are still high, and are generally related to ineffective management techniques. Moisture content at harvest varies between 40% and 45%, whereas the higher heating value is slightly lower than that of forest fuels. Comminuted vineyard residues are unsuitable for firing residential boilers, due to the frequent presence of oversize and/or undersize particles. The application of pesticides does not result in any significant contamination with noxious chemicals, because these products are almost completely weathered before residues are recovered. In wine-producing regions, the recovery of vineyard pruning residue may represent a substantial source of industrial bio-fuel.

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1. Introduction

Originating thousands of years ago in the Mediterranean, the cultivation of grapes is now common all over the world and often represents a very profitable endeavor. In 2008, the surface covered with vineyards amounted to almost eight million hectares worldwide [1]. This crop requires much tending, including annual pruning. That generates a substantial amount of residues, which must be disposed of before implementing any other tending measures. Finding some use for vineyard pruning residues would allow converting a disposal problem into a collateral production, with a potential for revenues or reduced management cost. Pruning residue harvesters have been developed, which may effectively recover vineyard pruning residues and make them available to the markets [2]. Vineyard pruning residues could partly replace traditional wood assortments for energy and industrial use [3], and they may play an important subsidiary role in supplying bioenergy plants with renewable fuel [4], especially in rural areas and where the forest resource is scarce. On the other hand, vineyard pruning residues have peculiar quality characteristics compared to other ligno-cellulosic feedstock, which may affect the choice and the performance of the conversion technology [5], as well as the potential for co-firing [6]. In general, wood fuel characteristics have a significant impact on the yield, quality and stability of both syngas [7] and pyrolysis oil [8]. Although particularly efficient [9], the newest small scale gasification technologies are especially sensitive to wood fuel characteristics [10]. Nor can one think about targeting high-quality wood fuel only, because the growing demand for wood fuels must be matched by an expanding supply, in order to guarantee price stability [11]. This is crucial to the development of the biomass energy sector, where fuel represents a major cost item [12]. Hence the interest in determining the main quality characteristics of most wood fuels, including vineyard pruning residues. In particular one should determine: particle size distribution, calorific value, moisture content and the potential for chemical contamination.

Particle size distribution is crucial to fuel handling efficiency [13], to its drying and reaction rate [14], to the energy required for conversion into ethanol [15], and to the yield of bio-oil obtained from pyrolysis [16]. Calorific value is the essential quality of any fuel, and is

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relatively constant for wood fuels in their dry status [17]. In this respect, moisture content is the most important physical characteristic of wood fuels, and it depends on a number of factors, including the collection period, the handling system and the duration of the eventual storage [18]. As most agricultural crops, vineyards are sprayed with pesticides, which raises the question of chemical contamination. There is a growing concern about the permanence of these chemicals, which may not be completely removed through weathering. If so, chemicals could concentrate in the wood ash, preventing their use as a fertilizer.

Against this background, the Italian National Council for Research (CNR), the Foundation Edmund Mach (FEM) and the Council for Research in Agriculture (CRA) set out to determine the quantity and the quality of residues that can be obtained from the annual pruning of vineyards in Italy. Ten percent of the global area grown with vineyards is concentrated in Italy, which occupies the third place among the countries with the largest vineyard surface. Italian vineyards provide a good example of modern industrial plantations, and can be taken as a representative example. In particular, the study aimed at quantifying: (1) the available amount of pruning residues per hectare; (2) the harvesting losses; (3) the moisture content of the product before and after storage; (4) the particle size distribution obtained with different machines; (5) the higher heating value; (6) the eventual concentration of pesticides on vineyard pruning residues.

2. Materials and methods

Three different areas in northern and central Italy were sampled for determining the amount of pruning residues that can be harvested from one hectare of vineyard. To this purpose, seventeen fields were harvested with a range of machines currently available on the European market, during dedicated machine trials. Overall, seven different machines were tested. Tests took place within the scope of several machine trial projects, which explains the loose experimental design. This could not be accurately drawn at the beginning of the trials, because each test belonged to a separate project. However, all tests were conducted by the same principal investigators and with the same methods, which assured consistency. Hence the limited but clear variability in sample size and number, as well as the deviation of the overall design from the exact balanced ideal. Nevertheless, this study gathers a large number of samples and offers a comprehensive set of information, determined with scientific methods and so far unavailable to the international scholar. Statistical analysis demonstrated that this design was adequate for testing the main sources of variability, while too loose for detecting secondary effects.

2.1. Residue yield and harvesting losses

Residue yield was determined by measuring all the mass of residues extracted from fields of known surface area. Harvested area was determined with measure tapes and laser rangefinders. Residue yield was determined by weighing all loads with portable scales, which were calibrated by taking a subsample of the same loads to a certified weighbridge. This procedure offered information on the amount of residue technically available, net of harvesting losses.

Harvesting losses were determined on eight of the same seventeen fields. Five to six square sample plots were randomly placed on each field. The area of each plot was determined with a measure tape, and varied between 20 and 40 m^2, depending on field size and interrow spacing. All residues inside the plots were collected manually and weighed with a portable scale.

2.2. Moisture content

The moisture content of the product before and after storage was determined on 91 samples, obtained from the same fields mentioned above. Five additional samples were collected when chipping vineyard pruning residues stored four months in the form of bales. Each sample consisted of approximately 1 kg of chips, which were put in individual bags, duly tagged and dispatched to the laboratory. Moisture content was determined with the gravimetric method, according to European standard CEN/TS 14774-2.

2.3. Particle size distribution

The particle size distribution obtained with different machines was determined on 84 samples, representing eleven different machines. At least 5 samples were collected from each machine. Most of these samples came from the same seventeen fields mentioned above, although some of them were obtained from additional operations, where it was impossible to determine the surface and the amount harvested. Hence, these additional tests were excluded from the analysis of yields and harvesting losses, and were only used to obtain information on particle size distribution. This was done in order to expand the range of tested machines. In fact, particle-size distribution is especially affected by machine type [19], comminuting device [20], and tool conditions [21]. Particle size distribution was determined on 500 g subsamples with a certified screening device, according to the European Standard CEN/TS 15149-1:2006. Five sieves were used in order to separate the six following chip length classes: >100 mm, 100–63 mm, 63–45 mm, 45–16 mm, 16–3 mm, <3 mm. Each fraction was then weighed with a precision scale. For easier understanding, the different fractions were grouped into three functional classes: oversize particles (>63 mm), large chips (63–45 mm) accepts (45–3 mm) and undersize particles (<3 mm) [22]. This way one could easily check if the chips would qualify for the P45 class, fulfilling the particle size specifications set for residential users. According to European Standard CEN TS 14961, the P45 class identifies a biomass fuel with three conditional characteristics: (1) 80% of the total mass must consist of particles not longer than 45 mm; (2) particles longer than 63 mm must represent less than 1% of the total mass; (3) particles smaller than 1 mm must represent less than 5% of total mass.

2.4. Heating value

Higher heating value (HHV) was determined on 7 samples obtained from a subset of the original seventeen fields. HHV was determined according to the European Standard CEN/TS 14918. Samples were ground with a rotating-blade mill and compressed into one-gram sample pellets [23]. Pellets were burned into a IKA C 400 adiabatic bomb calorimeter. Before starting actual measurements, the calorimeter was checked with 16 individual calibration runs.

2.5. Concentration of pesticides

Chemical contamination by pesticide residues was determined on 21 samples collected from five fields, at two different times. The first batch was collected at the beginning of the pruning season and the second at its end, in order to test the effect of weathering on contamination levels. In northern Italy these two periods coincide with the months of December and March, respectively. These fields were not part of the original pool of seventeen fields mentioned above. However, all fields were similar in terms of size, grape varietal and plant layout, and were all managed with conventional techniques, which included regular spraying with pesticides. Organic vineyards were excluded from the sample, because the resources for chemical analyses were limited and it was deemed best to focus on the most common and potentially critical case (i.e. where spraying is allowed). Chemical analyses aimed at detecting sulfur, copper and 13 organic chemicals commonly found in vineyard pesticides, and whose concentrations are limited by current legislation.

2.6. Data analysis

All data were analyzed with the Statview advanced statistics software, in order to check the statistical significance of the eventual differences between treatments with ANOVA techniques. Data were plotted and visually checked for normality. Then, differences were tested according to Scheffe's test (ANOVA – post hoc comparisons). This test is very robust and may be used when sample size is unbalanced and/or heteroscedastic. It is also the most robust against possible violations of the normality assumption [24].

3. Results

Table 1 shows the residue yields of the seventeen sample fields. The average amount of harvested residues was 2 fresh tonnes or 1.13 oven-dry tonnes (odt) per hectare. Tested at the 5% level, differences between varietals lacked any statistical significance, except for Prosecco, which offered a lower yield than all other varietals on trial. However, Prosecco was the only varietal in the test that had been pruned mechanically, and the significantly lower yield was most likely related to the pruning technique, rather than to the varietal. Mechanical pruners cut the vine branches in a number of small pieces, which fell right at the foot of vines. Both the reduced size and the position at the sides of the inter-rows made it difficult for most harvesting machines to recover the cut branches. In contrast, manual pruning left the cut branches in one long piece, which the pruning operators threw at the center of the inter-row, thus favoring subsequent collection.

The analysis of harvesting losses confirmed the effect of pruning technique (Table 2 and Fig. 1). There were significant differences between varietals, which could be divided in three groups: the first included manually pruned Merlot and Raboso, with harvesting losses in the range of 17%; manually pruned Cabernet and Sauvignon formed the second group, with harvesting losses between 32% and 37%; manually pruned Prosecco was wedged between these two groups, with average losses at 27%. However, the losses of mechanically pruned Prosecco soared to 48%, which could explain the significantly lower yields obtained from mechanically pruned Prosecco fields. Harvesting machine type did not have any significant impact on harvesting losses.

Table 2
Harvesting losses in% over the total amount of residues on the ground.

Varietal	Mean	Std. Dev.	Count	Min	Max	Pruning method
Cabernet	37.3^{a}	8.8	8	29.0	56.3	Manual
Merlot	17.8^{b}	7.1	8	5.9	25.9	Manual
Prosecco	26.9^{ab}	5.5	4	20.1	33.4	Manual
Prosecco	47.9^{c}	5.9	9	37.7	55.2	Mechanized
Raboso	17.5^{b}	4.3	8	10.8	25.9	Manual
Sauvignon	32.6^{a}	9.7	4	19.0	39.9	Manual

Note: Different letters on the mean values indicate that differences are statistically significant at the 5% level.

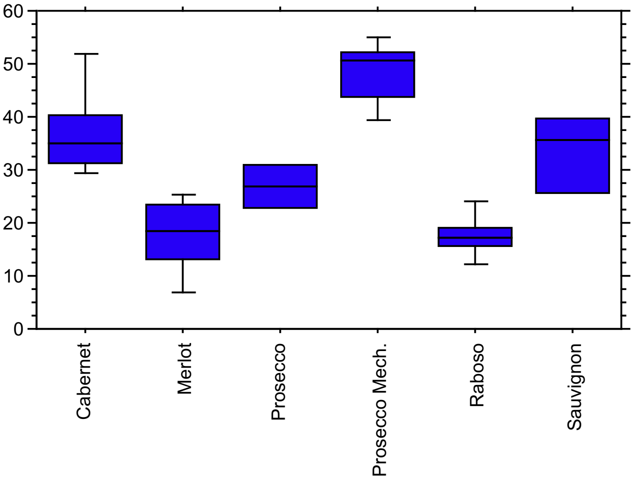

Fig. 1. Harvesting losses in%, as a function of grape varietal and pruning technique.

Table 3 shows the results of moisture content analyses. Data were grouped by farm, on the assumption that moisture content was related to the weather in each specific location, and to the delay between pruning and harvesting. These parameters were considered constant for each given farm and location. Although the collection time was obviously known, no exact information was consistently available about pruning time, so that the effect of harvesting delay

Table 1
Amount of harvested residue.

Field	Varietal	Machine	ha	*t*	m.c.	odt	*t* ha^{-1}	odt ha^{-1}	Pruning
1	Cabernet	A	1.64	4.8	45.7	2.6	2.90	1.57	Manual
2	Cabernet	B	1.15	3.5	45.1	1.9	3.00	1.65	Manual
3	Cabernet	C	0.90	2.3	45.8	1.3	2.58	1.40	Manual
4	Cabernet	D	1.24	2.2	46.6	1.2	1.76	0.94	Manual
5	Merlot	D	1.59	2.7	46.4	1.4	1.70	0.91	Manual
6	Merlot	A	3.59	7.0	46.8	3.7	1.95	1.04	Manual
7	Merlot	E	0.95	2.0	39.0	1.2	2.11	1.28	Manual
8	Merlot	B	1.66	3.5	38.9	2.1	2.11	1.29	Manual
9	Merlot	F	0.61	1.2	39.8	0.7	1.97	1.18	Manual
10	Merlot	C	1.32	2.8	44.6	1.5	2.11	1.17	Manual
11	Prosecco	A	2.00	3.3	37.7	2.1	1.65	1.03	Mechanized
12	Prosecco	B	1.16	1.1	34.9	0.7	0.91	0.59	Mechanized
13	Prosecco	D	1.13	1.1	39.3	0.7	0.97	0.59	Mechanized
14	Verduzzo	C	2.14	4.3	44.8	2.4	2.00	1.10	Manual
15	Verduzzo	G	3.29	7.4	44.8	4.1	2.26	1.25	Manual
16	Verduzzo	B	1.79	3.6	44.8	2.0	2.03	1.12	Manual
17	Verduzzo	E	3.00	5.7	44.8	3.2	1.92	1.06	Manual
		Sum	29.15	58.5		32.8			
		Mean			42.9		**2.00**	**1.13**	
		Std. Dev.			3.7		0.55	0.28	

Note: The amounts in the table represent the actual amount harvested, net of losses, and not the potential biometric availability.

Table 3
Moisture content (% on wet basis) of vineyard pruning residues.

Farm	Varietal	Mean	Std. Dev.	Count	Min	Max	Material
1	Merlot	39.2^a	1.9	16	34.9	43.4	Fresh
2	Prosecco	24.5^b	5.9	5	13.8	27.7	Stored
3	Cabernet	45.8^c	2.5	17	38.4	48.8	Fresh
4	Verduzzo	44.8^c	1.6	15	42.2	47.4	Fresh
5	Merlot	44.4^c	2.3	10	40.4	47.3	Fresh
6	Cabernet	40.0^a	2.0	28	35.7	43.8	Fresh
7	Prosecco	40.2^a	4.5	5	34.8	46.5	Fresh
All		41.3	5.3	96	13.8	48.8	

Note: Different letters on the mean values indicate that differences are statistically significant at the 5% level.

Table 5
Effect of refining devices on particle size distribution.

	Facma Machine			Peruzzo Machine		
	Standard	Refining	*p*	Standard	Refining	*p*
Oversize (%)	47.0	8.5	0.001	9.5	2.7	0.017
Large chips (%)	10.5	6.2	0.220	5.3	5.6	0.664
Accepts (%)	36.7	71.5	0.001	82.9	83.4	0.664
Undersize (%)	5.8	14.9	0.020	2.2	8.5	0.001

Note: *p*-values refer to the differences between the mean incidence of each particle size class recorded for the standard version of the machine, and the version equipped with a refining device (i.e. screen for machine A; improved counter-knives for machine D).

could not be tested. The residues obtained on farm 2 had been harvested 4 months before chipping, and had been stored as bales under a roof. The average moisture content of fresh material harvested between February and March varied between 40% and 45% on a wet basis, with significant differences between farms. Baled residues stored under a roof and chipped in July had a moisture content of 24.5%.

Particle size distribution was very variable, but none of the tested machines offered P45 class chips (Table 4). In fact, only 2 samples on 84 fulfilled P45 specifications, qualifying for residential use. All the other samples contained an exceedingly large proportion of oversize and/or undersize particles. The oversize fraction was especially large for shredders without any refining device, such as screens or counter-knives. However, machines equipped with refining devices produced a larger amount of undersize particles, compared to simpler units. Table 5 shows a direct comparison between the same two machines, with and without a refining device. In both cases, the application of a refining device caused a reduction in the proportion of oversize particles, and a parallel increase in that of undersize particles. Both changes were statistically significant. When the incidence of oversize particles falls below 5%, that of undersize particle increases dramatically (Fig. 2).

On average, the higher heating value of vineyard pruning residue was 18.7 MJ kg^{-1}, with very little variation between samples (Table 6). Once the effect of moisture content was removed, vineyard pruning residues offered a rather homogenous fuel, at least in term of higher heating value.

Chemical analyses of pruning residues detected 15 different pesticides used in conventional vineyards (Table 7). However, the concentration of these pesticides was very weak. To represent the worst case, the maximum concentration found in the samples for any one chemical was compared with the legal limit for that same chemical. Except for copper, the maximum concentration found in the samples was many times (5–500) smaller than the legal limit. The maximum value for copper was still below the legal limit, but the ratio was only 0.9. Some chemicals weathered very quickly, and by March their concentration was equal or near to zero. This was the case of Folpet, Dithiocarbamates, Boscalid and Azoxystrobin. Sulfur also met with rapid dilution. In contrast, other chemicals were more persistent and their concentration could-increase with time.

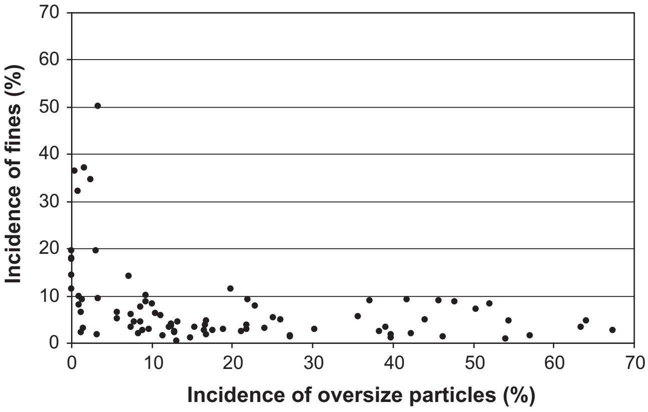

Fig. 2. Relationship between the proportions of undersize and oversize particles.

4. Discussion

The residue yields reported in this study find an almost perfect match in the figures reported by Laraia et al. [25] in their study for the Italian Environmental Protection Agency. Similar figures were also reported by Di Blasi et al. [26]. Hence, there is a general agreement about the amount of pruning residues that can be recovered from vineyards. It is important to stress that these yields are net of harvesting losses, which are relatively high. Harvesting losses could be reduced through a better management of the residues, which is likely to occur if recovery will become common practice. Growers are not yet familiar with pruning recovery operations, and often reduce cut branches in smaller pieces, or fail to bunch them at the center of the inter-row. These are main causes of harvesting

Table 4
Particle size distribution: average by machine type.

Machine ID	Power (kW)	Comminuter type	Refiner type	Count (*n*)	Oversize (%)	Large chips (%)	Accept (%)	Undersize (%)
Heizohack	236	Chipper	Screen	5	0.0^a	23.0^a	60.8^a	16.2^a
Omat	66	Shredder	Screen	5	5.4^b	1.6^b	53.5^a	39.5^b
Peruzzo	59	Cutter	Counter-knife	15	9.5^b	5.3^b	83.0^a	2.2^c
Berti	66	Shredder	Screen	10	11.9^b	13.0^b	68.7^a	6.4^c
B3	66	Shredder	Screen	5	14.5^b	10.5^b	71.3^a	3.7^c
Tierre	55	Shredder	Screen	5	17.0^b	14.4^b	63.7^a	4.9^c
Nobili	66	Shredder	Counter-knife	10	18.7^b	10.2^b	67.1^a	4.0^c
Ubaldi	55	Shredder	Screen	5	22.5^b	12.0^b	62.1^a	3.4^c
Orsi	59	Shredder	None	5	33.6^c	17.5^b	45.7^a	3.2^c
Facma	63	Shredder	None	15	47.0^d	10.5^b	36.7^b	5.8^c
Dragone	55	Shredder	None	5	58.6^d	6.4^b	30.9^b	4.1^c

Note: Letter codes for machine ID correspond to those reported in Table 1, and when identical identify the same machine; different letters on the mean values indicate that differences between machines are statistically significant at the 5% level.

Table 6
Higher heating value (HHV) of vineyard pruning residues.

Sample #	Field #	Total sample weight (g)	Weight of wood (g)	Weight of ignition wire (g)	Weight of unburned ign. wire (g)	Δt (°C)	Total HHV (MJ kg^{-1})	Net HHV (MJ kg^{-1})
1	5	1.000	0.991	0.009	0.002	2.041	17.8	17.8
2	5	1.078	1.069	0.009	0.002	2.288	18.5	18.5
3	6	0.987	0.978	0.009	0.003	2.112	18.7	18.6
4	7	1.037	1.029	0.008	0.002	2.258	19.0	18.9
5	7	1.059	1.050	0.009	0.002	2.334	19.2	19.2
6	8	1.065	1.056	0.009	0.003	2.343	19.2	19.2
7	9	1.121	1.112	0.009	0.001	2.425	18.8	18.8
						Mean		**18.7**
						Std. Dev.		0.5

Notes: Field numbers correspond to those in Table 1; the calorific value of the ignition wire is 7.7 MJ kg^{-1}.

Table 7
Concentration of selected pesticides in the pruning residues (mg kg^{-1}).

Compound	Legal limit	Maximum		Limit/Max ratio	Mean		
		December	March		December	March	*p*
Sulfur	50	2.40	0.90	21	0.88	0.19	**0.032**
Copper	20	14.20	17.90	1	8.86	11.22	0.159
Folpet	5	0.40	0.00	13	0.08	0.00	**0.056**
Dithiocarbamates	5	0.75	0.00	7	0.39	0.00	**<0.001**
Fenhexamid	5	0.02	0.03	167	0.00	0.00	0.937
Ciprodinil	5	0.03	0.08	63	0.01	0.01	0.855
Fludioxonil	2	0.01	0.02	100	0.00	0.00	0.799
Pyrimethanil	5	0.01	0.00	500	0.00	0.00	0.258
Mepanipyrim	3	0.02	0.02	150	0.00	0.00	0.923
Boscalid	2	0.10	0.03	20	0.03	0.01	**0.048**
Dimethomorph	0.5	0.02	0.03	17	0.01	0.01	0.595
Azoxystrobin	2	0.02	0.00	100	0.01	0.00	**0.004**
Pyraclostrobin	2	0.03	0.00	67	0.00	0.00	0.258
Penconazole	0.2	0.01	0.00	20	0.00	0.00	0.258
Ethylphosphonic acid	0.05	0.01	0.00	5	0.00	0.00	0.258

Notes: The legal limit for the concentration of pesticides is that prescribed by the Italian law (which conforms to European Union directives) for wine grapes; the Limit/Max ratio is obtained by dividing the legal limit by the highest value obtained for residue concentration in any of the 21 samples; *p* is the significance value for the test comparing the means of December and March; italics *p*-values indicate a difference significant at the 5% level.

losses, especially if the inter-rows are wide. In such instances, harvesting losses could be reduced with a double-pass or with preliminary windrowing, but both solutions are likely to cost more than they accrue. Improved technology could also contribute to reduced losses, and some manufacturers are already equipping their pruning residue harvesters with optional front brushes, designed to move scattered residues to the center of the row and towards the harvester pick-up device. Otherwise, one may also think about developing single-pass pruning and recovery units, as already done for olive tree plantations [27].

The moisture content of fresh vineyard pruning residues is relatively high, yet lower than that of freshly felled short rotation poplar [28]. Moisture content decreases after cutting, and residues collected in late winter or early spring could be drier than those harvested in mid-winter, right after pruning. However, the time available for harvesting pruning residues is already very short, because pruning does not start much earlier than December, and the fields must be cleared by the end of March, at latest. Therefore, it would be unrealistic to suggest that residue is left in the field until late March, in order to reduce its moisture content. In fact, collection must begin as soon as the pruning is available, in order to run the equipment at least three months per year. If a dry fuel is needed, active drying could be considered. Otherwise, residues can be compacted and stored as bales: that will allow effective natural drying, but will require additional handling and the resulting additional cost.

Processed vineyard pruning residues contain very large proportions of oversize and/or undersize particles. That makes them more suitable for industrial use, than for residential use. In fact, several vineyard growers harvest and use their own residues for residential heating, showing that conversion in small plants is technically viable. However, it would be very difficult for these growers to offer their product on the residential market and outcompete better forest fuels, unless they were ready to accept substantially lower prices [29]. In any case, the current demand of the residential sector is much smaller than that of the industrial sector [26]. This is unlikely to change in the near future, due to the strong emphasis placed on power generation by European policy makers [30,31]. Hence, the large amount of biomass potentially recovered from vineyard pruning residues could exceed the demand for residential heat. On the contrary, tapping new and unused resources for the industrial bioenergy sector may palliate the stinging competition between energy and industrial users [32]. The expected rapid growth of the biomass sector requires expanding fuel supply beyond the narrow limits of industrial wood residues [33], which are also the main source of raw material for pellet manufacturing [34]. If vineyard pruning residues are recycled as industrial biomass fuel, then it would make sense to avoid any drying delays and deliver the product immediately after harvesting. Industrial plants can cope with a 40% moisture content, and in that case drying would only make the supply chain more costly and complicated than strictly needed.

The HHV of vineyard pruning residues is slightly lower than that of forest trees, which was determined by the same authors with the same procedure and equipment, and resulted equal to 19.4 and 20.2 MJ kg^{-1}, respectively for broadleaved and conifers [35]. The higher heating value of conifer wood is well attested in literature [36], and is naturally related to its high resin content

[37]. As to broadleaved, they perform better than vineyard pruning residues, but the difference is small (although significant; $p = 0.004$). In this respect, it would be interesting to gather additional information about ash content, which was not determined in this study. Vineyard pruning residues are used for traditional cooking and have a reputation for producing much ash. Further research could check whether this depends on the inefficient performance of traditional ovens, or if it is an inherent quality of vineyard residues, which will manifest even when resorting to better combustion technology.

Vineyard pruning residues retain minimal amounts of the pesticides sprayed during the growing season. By the time residues are collected, these chemicals are almost totally weathered, and their concentration is much below the legal limits. However, one must notice that the legal limits used in this study are those issued for the grapes, not for the pruning residues. Apparently, no laws prescribe any legal limits for the pesticides contained in fuel wood. User plants must comply with limits imposed on emissions, but as far as fuel is concerned, the divide is between treated and untreated. It is common understanding that treated stands for painted or impregnated with preservatives, and the amount of pesticides contained in vineyard pruning residues is so small that these may lack both qualifications. However, one might check what happens to these chemicals during combustion, and especially if they are completely degraded, or if they are concentrated in the ashes (and in what form). CNR is working on a new project to define these important questions. Finally, the concentration of some chemicals increases with time, because it is always calculated on a fresh weight base, and the residues get lighter as they dry. Hence, the increased concentration registered in March for some chemicals only means that between December and March the residues lost proportionally more moisture than chemical, and not that the residues were further contaminated.

5. Conclusions

The annual pruning of vineyards generates a substantial amount of ligno-cellulosic material, which can be recovered and processed into biomass fuel using commercial pruning harvesters. Net residue yield varies around 1 odt ha^{-1}, and could increase if harvesting losses were reduced. The heating value of vineyard pruning residues is slightly lower than that of forest fuels. Comminuted vineyard residues are unsuitable for firing residential boilers, due to the relatively high moisture content and the frequent presence of oversize and/or undersize particles. On the other hand, they can offer an acceptable industrial fuel. Concentration of vineyards in vocated wine-growing regions may help in generating the critical mass needed for targeting the industrial user. The application of pesticides does not result in any significant contamination with noxious chemicals, because these products are almost completely weathered before residues are recovered. Hence, vineyard pruning residue may satisfy the legal requirements for clean biomass fuel, free from chemical contaminants.

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